

ASEN 6519: SPECIAL TOPICS

HYBRID SYSTEMS: THEORY, COMPUTATION, AND APPLICATIONS

SPRING 2024

LECTURE INFORMATION

Monday and Wednesday 1:00-2:15pm

Room: AERO 232

Video recording will be made available after each lecture on the course canvas page

INSTRUCTOR

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Office hour: Wednesday 1:30-2pm and by appointment

COURSE DESCRIPTION

In many modern engineering applications -- robotics, automation, real-time software, aeronautics, air and ground transportation systems, systems biology, and process control, to name a few -- the states of the system undergo a mixture of real-time (continuous) and instantaneous event (discrete) transitions. This mixture can be dictated by the fundamentally non-smooth or discontinuous nature of some physical phenomena (e.g., mechanical impact, network rerouting, and cell differentiation) or intentional by design (e.g., integration of discrete logic or digital computers with continuous physical processes). The result of such a coupling of discrete and continuous dynamics is a hybrid system. More specifically, hybrid systems are continuous variable systems with a phased operation, capturing both discrete event (linguistic behavior) and "lower-level" continuous behavior of the system. For this very reason, hybrid systems have recently been at the center of intense research activity in the control theory, computer-aided verification, and artificial intelligence communities.

This course provides an introduction to hybrid systems. We start by presenting a modeling framework for hybrid systems that combines elements from automata theory and differential equations. We then introduce a set of techniques that can be used for design and analysis of hybrid systems. We also present recent advances in the theory for formal verification and control

of these systems and show the applications of the theory to the design of the control architecture for complex and uncertain systems.

This course is designed to be aligned with the objectives of the CEAS's Autonomous Systems Interdisciplinary Research Theme and is open to AES, CS, ME, and ECEE students.

PREREQUISITES

Hybrid systems contain both continuous and discrete dynamics. This implies that this course builds on both continuous and discrete mathematics. Prerequisites includes linear algebra, differential equations, linear control systems, and some scientific programming language (e.g., MATLAB).

GRADING AND EVALUATION

Classwork consists of some homework exercises worth 40%, a paper presentation and participation in the class discussion 15%, and a substantive project worth 45% of the grade.

COURSE TEXTBOOKS

The course is essentially self-contained, and no textbook is required.

Recommended readings:

- Formal methods for discrete-time dynamical systems
C. Belta, B. Yordanov, and E. Gol
Springer
2017
- Verification and control of hybrid systems: a symbolic approach
P. Tabuada
Springer Science & Business Media
2009
- Hybrid Systems: Foundations, advanced topics and applications
J. Lygeros, S. Sastry, and C. Tomlin
2021

COURSE OUTLINE

- Introduction, motivation, and examples
- Mathematical background
- Trajectories of hybrid systems
- Existence of Executions
- Stability of hybrid systems
- Formal analysis and control of dynamical systems
 - Transition systems, simulations, and bisimulations
 - Temporal logics
 - Model checking and verification
 - Analysis and control for finite systems
 - Analysis and control for continuous-time dynamical systems
 - Analysis and control for discrete-time dynamical systems
- Stochastic Hybrid Systems
- Applications
 - Symbolic motion planning and control
 - Sampling-base motion planning

CLASSROOM BEHAVIOR

Students and faculty are responsible for maintaining an appropriate learning environment in all instructional settings, whether in person, remote, or online. Failure to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation, or political philosophy.

For more information, see the [classroom behavior policy](#), the [Student Code of Conduct](#), and the [Office of Institutional Equity and Compliance](#).

REQUIREMENTS FOR INFECTIOUS DISEASES

Members of the CU Boulder community and visitors to campus must follow university, department, and building health and safety requirements and all public health orders to reduce the risk of spreading infectious diseases.

The CU Boulder campus is currently mask optional. However, if masks are again required in classrooms, students who fail to adhere to masking requirements will be asked to leave class. Students who do not leave class when asked or who refuse to comply with these requirements will be referred to Student Conduct & Conflict Resolution. Students who require accommodation because a disability prevents them from fulfilling safety measures related to infectious disease

will be asked to follow the steps in the “Accommodation for Disabilities” statement on this syllabus.

For those who feel ill and think you might have COVID-19 or if you have tested positive for COVID-19, please stay home and follow the [further guidance of the Public Health Office](#). For those who have been in close contact with someone who has COVID-19 but do not have any symptoms and have not tested positive for COVID-19, you do not need to stay home.

ACCOMMODATION FOR DISABILITIES, TEMPORARY MEDICAL CONDITIONS, AND MEDICAL ISOLATION

[Disability Services](#) determines accommodations based on documented disabilities in the academic environment. If you qualify for accommodations because of a disability, submit your accommodation letter from Disability Services to your faculty member in a timely manner so your needs can be addressed. Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance.

If you have a temporary medical condition or required medical isolation for which you require accommodation, contact the faculty instructor immediately. For assignment or exam accommodations, notify the faculty at least three weeks prior to the due date or exam date. Also see [Temporary Medical Conditions](#) on the Disability Services website.

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PREFERRED STUDENT NAMES AND PRONOUNS

CU Boulder recognizes that students' legal information doesn't always align with how they identify. Students may update their preferred names and pronouns via the student portal; those preferred names and pronouns are listed on instructors' class rosters. In the absence of such updates, the name that appears on the class roster is the student's legal name.

HONOR CODE

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the [Honor Code](#). Violations of the Honor Code may include but are not limited to: plagiarism (including use of paper writing services or technology [such as essay bots]), cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course without permission from all course instructors involved, and aiding academic dishonesty.

All incidents of academic misconduct will be reported to Student Conduct & Conflict Resolution: honor@colorado.edu, 303-492-5550. Students found responsible for violating the [Honor Code](#) will be assigned resolution outcomes from the Student Conduct & Conflict Resolution as well as be subject to academic sanctions from the faculty member. Visit [Honor Code](#) for more information on the academic integrity policy.

SEXUAL MISCONDUCT, DISCRIMINATION, HARASSMENT AND/OR RELATED RETALIATION

CU Boulder is committed to fostering an inclusive and welcoming learning, working, and living environment. University policy prohibits [protected-class](#) discrimination and harassment, sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, and related retaliation by or against members of our community on- and off-campus. These behaviors harm individuals and our community. The Office of Institutional Equity and Compliance (OIEC) addresses these concerns, and individuals who believe they have been subjected to misconduct can contact OIEC at 303-492-2127 or email cureport@colorado.edu. Information about university policies, [reporting options](#), and support resources can be found on the [OIEC website](#).

Please know that faculty and graduate instructors have a responsibility to inform OIEC when they are made aware of incidents related to these policies regardless of when or where something occurred. This is to ensure that individuals impacted receive an outreach from OIEC about their options for addressing a concern and the support resources available. To learn more about reporting and support resources for a variety of issues, visit [Don't Ignore It](#).

RELIGIOUS HOLIDAYS

Campus policy regarding religious observances requires that faculty make every effort to deal reasonably and fairly with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. In this class, inform the instructors of such conflicts at least three weeks in advance.

See the [campus policy regarding religious observances](#) for full details.

MENTAL HEALTH AND WELLNESS

The University of Colorado Boulder is committed to the well-being of all students. If you are struggling with personal stressors, mental health or substance use concerns that are impacting academic or daily life, please contact [Counseling and Psychiatric Services \(CAPS\)](#) located in C4C or call (303) 492-2277, 24/7.

Free and unlimited telehealth is also available through [Academic Live Care](#). The Academic Live Care site also provides information about additional wellness services on campus that are available to students.